COMPARISON OF POLYSTYRENE EXPANDED AND EXTRUDED FOAM INSULATION IN ROADWAY AND AIRPORT EMBANKMENTS

FINAL PROJECT REPORT

by

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DISCLAIMER

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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Abstract

The differences in performance of expanded polystyrene rigid foam insulation (EPS) and extruded polystyrene rigid foam insulation (XPS) has been debated since the 1980's. Esch's 1986 study showed that the R-value of EPS degraded more than XPS when installed in roadway embankments. Pouliot and Savard (2003) noted similar results. This study adds 15 additional samples from three additional installations to the dataset. Using the combined data from these sites, ratios of R-values of EPS/XPS were developed which can be used to estimate equivalent thicknesses of the two products. R-value multipliers were also developed which allow thicknesses of the products to be computed based on the long-term performance of the insulation used in roadway and airport embankments. The data appear to be consistent between Esch, Pouliot and Savard and this study. There is no consensus as to how the data or ratios are to be applied if at all. However, the study does provide two approaches. A multiplier can be applied to each product which provides a long-term equivalent thickness for each product. Alternatively, a multiplier can be applied to the R-value of each product which yields a thickness that yields a long-term R-value of in-service applications.

CHAPTER 1. INTRODUCTION

The first use of insulated roadways over permafrost in North America was near Chitina, Alaska, in 1969 by the Alaska Department of Highways (Esch December 1986). Later that year an airfield runway was insulated at Kotzebue, Alaska. Since then, insulation has been used in roadways for preserving permafrost, for reducing frost heave, and as lightweight fill. In this report, lightweight fill will not be discussed.

Two types of polystyrene rigid-board foam are commonly used in embankments: extruded foam board (XPS) and expanded foam board (EPS). The manufacturers of both XPS and EPS have aggressively marketed their products, claiming their respective products are superior. While several studies show the benefits of using rigid insulation over the short term, few studies report long-term performance in roadway and airport embankments. Fewer studies have recovered the insulation and measured its R-value after years of service. As a result, most agencies simply rely on the initial R-value of the product when computing the required thickness of the insulation.

In Esch's 1986 landmark study, 18 insulation samples were recovered from 8 installations in Alaska (Esch December 1986). Twelve samples from 6 sites were extruded foam, with a maximum age of 20 years and an average age of 9 years. The water content averaged 1.16% by volume, ranging from 0.23% to 2.38% by volume. In contrast, the expanded insulation (described by Esch as BeadBoard) was between 3 and 15 years in age with an average moisture of 2.9% by volume, ranging from 1.18% and 5.88% by volume. Esch reported an average long-range of R-value for extruded polystyrene foam as 3.9 and a long-range R-value for expanded polystyrene of 2.6. From these values, Esch concluded ,"*If this ratio is based on average rather than minimum R-values, a thickness ratio of 1.36 to 1 is indicated; however, a ratio this low would be unfair to extruded foams, which are more consistent and better able to resist gains and R-value losses with time in service." (Esch, December 1986, page 8)*

Pouliot and Savard (2003) evaluated the performance of EPS and XPS insulation in Quebec, Canada, to determine the impact of insulation on roadway performance, including transverse cracking, fatigue cracking, centerline cracking, and total cracking. Since the insulation was used primarily for reduction of frost heave, the depth of freeze was also monitored. The data of interest here are the water uptake and the conductivity of the insulation. The authors tested the water absorption using ASTM D2842 and stated, "*We note that the expanded polystyrene absorbs 5% water by volume after only 10 days. The absorption then decreases considerably, reaching a value of 6.2% after an immersion time of 200 days."(Pouliot and Savard, 2003, page 19)* The HI-60 extruded polystyrene absorbed only 2% moisture by volume after 200 days. These values are within the range reported by Esch.

Pouliot and Savard also recovered in situ samples of EPS and XPS from the roadway at 1, 3, 5, and 7 years and determined the thermal conductivity of each of the samples and a sample collected at the time of construction. The authors concluded that thermal conductivity averaged 0.036 W/K.m for EPS and 0.030 W/K.m for XPS over the 7-year observation period. From these findings, the authors noted that the thickness of EPS would need to be increased by 20% to obtain the same thermal performance as XPS. The values obtained in the laboratory of 0.036 for EPS and 0.030 for XPS result in a ratio of 1.23, which is nearly the same as the field ratio. This finding is similar to the results reported by Esch of 1.36

While the existing data set is small, it is consistent in showing that an equivalent long-term R-value for EPS requires a thickness between 1.2 and 1.3 times the thickness of XPS. Further, the data presented by Esch indicate that EPS has greater moisture uptake than XPS over time. It is interesting to note that, based on the existing literature, moisture content has a greater impact on R-value for EPS than for XPS.

Cai, Zhang, and Cremaschi (2017) explored the use of EPS and XPS used in below-grade applications based on existing literature. While their work focused on building applications, the concepts they propose are useful. They point out that in building insulation, three phenomena occur: absorption, capillary action, and diffusion. Between 0 and 30% relative humidity, absorption processes dominate. When the relative humidity exceeds 80%, capillary action takes over.

Cai et al (2017) noted that there is no apparent correlation between the 24-hour water immersion test and EPS moisture behavior in frost applications beyond 6 years of service. However, ASTM C272 24-hour and ASTM D2842 4-day water immersion appears to yield water content close to the in-service of less than 6 years for EPS. The 4-day immersion tests tend to slightly underpredict the moisture content for XPS for the same in-service period. Based on this, immersion tests should not be expected to accurately predict the long-term performance of either EPS or XPS in roadways. However, ASTM D2842 4-day water immersion test can be used as a quality control test.

Neither Esch nor Pouliot and Savard attempted to explain how the insulation absorbs water or why the variability of moisture uptake of water occurs. Unfortunately, while moisture uptake in insulation used in buildings has been researched, the mechanisms of moisture uptake in insulation placed in soils are not understood. It is tempting to apply the vapor transport mechanisms described in building literature to soil applications, but moisture transport in soils is much more complex. In building applications, the vapor transport is a function of vapor pressure, which is related to relative humidity on each side of the wall, the temperature gradient, and the permeability of materials in the wall.

In soils, moisture movement is related to soil gradation, soil moisture content, soil suction, and temperature gradient. As soil approaches saturation, gravity increasingly becomes the primary driving force. As soil dries, soil suction increasingly becomes the driving force. Since soil suction is a function of moisture content and temperature gradient, one would expect the vapor pressure to increase as the soil dries and cools. Two examples illustrate this phenomenon.

The first occurs in desert climates such as those found in Arizona. During the heat of the day, water vapor moves upward in the embankment until it hits the impermeable pavement surface, where it condenses as the pavement cools in the evening. As a result, the strength of the base course may be compromised.

In cold regions, including the northern states, moisture in the soil is drawn upward in the soil column through capillary action and vapor transport due to the thermal gradient in the soil. The moisture then freezes as it reaches the freezing front, resulting in frost heave over the winter and thaw weakening in the spring. Moisture movement through capillary action occurs predominantly in fine-grained soil. Vapor transport is more likely to occur in sandy or gravelly soils. Vapor transport is a minor contributor in frost heave; however, it may be more important in moisture uptake in insulation as evidenced by moisture uptake in building envelopes due to vapor transport.

Unsaturated soil mechanics seek to explain the properties of soils as a result of moisture content below the saturation point. This explanation requires an understanding of moisture movement resulting from soil suction. Further soil suction also impacts soil strength directly. For example, vertical surfaces in non-plastic silty soils can only be explained by soil suction. Unsaturated soil mechanics has only recently become mature enough to apply to engineering practice. Unfortunately, this knowledge has not been applied to the use of insulation in soils. As a result, this study cannot fully explain the mechanisms related to the performance of rigid polystyrene insulations in roadway and airport applications.

This study has four primary focal points, recognizing the lack of understanding of moisture uptake:

1. Increase the number of data points by recovering in situ insulation and determining the moisture content and the in-situ R-value.
2. Determine whether recent changes in the production of EPS rigid foam insulation used in Alaska has altered the performance of the product.
3. Revisit the existing data in concert with new data to better understand the relationship of in-service insulation and R-value with time.
4. Recommend a strategy for incorporating rigid foam insulation into roadway projects accounting for in-service performance.

The goal is not to prove one product is necessarily better than the other. Rather, it will be left to the user to determine the best product for an application based on cost and availability. The user should account for the change in R-value as a function of moisture content over time, which is different for each product. The uptake of moisture is clearly different in each product. Based on these characteristics, the design thickness may be different for each product.

CHAPTER 2. DATA COLLECTION

Part of this effort was to add additional data to the data set to increase the range of long-term performance curves for rigid foam insulation and to determine if recent modifications consisting of coating the upper and lower surfaces of the EPS with a sealant in the manufacture of expanded foam insulation had changed performance since previous studies. Additional insulation samples were collected from three sites:

1. Dalton Highway at approximately mile 10, originally placed in 2013 (EPS)
2. Cripple Creek on / near the beginning of Chena Ridge Road, Fairbanks, originally placed in 1997 (EPS)
3. Golovin Airport, Golovin, Alaska, originally placed in 1987 (XPS)

Samples were collected by excavating the rigid board insulation and double sealing each sample in a polyethylene bag. The samples were then shipped to a third-party testing laboratory. Thermal testing was completed in accordance with ASTM C518. All samples were tested as received, after trimming ¼ inch of material from each side. Trimming by removing ¼ inch of material from each face was done to remove soil contamination and surface damage from the sample. After thermal testing, each prepared sample was dried to constant mass to determine the moisture content. Finally, one sample from each location was tested for thermal properties after drying. The test results are provided in Appendices A and B. Table 1 and Table 2 summarize the results of this study, and include the data gathered by Esch (1986) and Pouliot and Savard (2003).

Table 1 XPS data from this study and from studies by Esch (1986) and Pouliot and Savard (2003)

Extruded Polystyrene Insulation									
Site	**Layer**	**Thickness (cm)**	**Year Placed**	**Years in Service**	**Insulation**	**Water by Volume (%)**	**Kave (BTU*in/(F*hr*ft2))**	**R-value per inch (F*hr*ft2)/BTU**	**Data Reported by**
Kotzebue	Top	5	1969	15	Extruded	2.38	0.2148	4.66	Esch
Kotzebue	Bottom	5	1969	15	Extruded	0.89	0.1940	5.15	Esch
Buckland	Top	7.5	1981	3	Extruded	0.41	0.2009	4.98	Esch
Buckland	Bottom	7.5	1981	3	Extruded	0.23	0.2079	4.81	Esch
Deering	Single	5	1981	3	Extruded	1.37	0.2009	4.98	Esch
Chitina	Top	5	1969	15	Extruded	0.71	0.2356	4.24	Esch
Chitina	Bottom	5	1969	15	Extruded	0.88	0.2564	3.90	Esch
Chitina	Single	5	1969	15	Extruded	1.54	0.2148	4.66	Esch
Bonanza Creek	Single	5	1974	10	Extruded	1.48	0.2494	4.01	Esch
Bonanza Creek	Single	5	1974	10	Extruded	2.38	0.2494	4.01	Esch
Fairhill	Top	5	1979	5	Extruded	0.5	0.2217	4.51	Esch
Fairhill	Bottom	5	1979	5	Extruded	0.2	0.2148	4.66	Esch
Chitina	Top	5	1969	25	Extruded	1.36	0.2356	4.24	Esch
Chitina	Bottom	5	1969	25	Extruded	1.72	0.2425	4.12	Esch
Bonanza Creek	Single	5	1974	20	Extruded	3.1	0.2633	3.80	Esch
Golivan 1		5	1987	31	Extruded	9.09	0.2400	4.17	This Study
Golivan 2		5	1987	31	Extruded	7.18	0.2540	3.94	This Study
Golivan 3		5	1987	31	Extruded	2.08	0.2250	4.44	This Study
Quebec Test			1995	1	Extruded	0.67	0.2009	4.98	Pouliot and Savard
Quebec Test			1995	3	Extruded	0.73	0.2079	4.81	Pouliot and Savard
Quebec Test			1995	5	Extruded	1.5	0.1940	5.15	Pouliot and Savard
Averages						**1.924**		**4.486**	
Std.Dev						**2.222**		**0.438**	
Coefficient of Variation						**1.155**		**0.098**	

Table 2 EPS data from this study and from studies by Esch (1986) and Pouliot and Savard (2003)

Expanded Polystyrene Insulation									
Site	**Layer**	**Thickness (cm)**	**Year Placed**	**Years in Service**	**Insulation**	**Water by Volume (%)**	**Kave (BTU*in/(F*hr*ft2))**	**R-value per inch (F*hr*ft2)/BTU**	**Data Reported by**
Fairhill	Single	10	1979	15	BB	1.48	0.291	3.44	Esch
Minnesota Dr.	Top	5	1981	3	BB	5.88	0.360	2.78	Esch
Minnesota Dr.	Bottom	5	1981	3	BB	2.9	0.263	3.80	Esch
Fairhill	Single	10	1979	15	BB	5.15	0.319	3.14	Esch
Dalton MP 9-18		7.6	2013	5	Expanded	11.41	0.320	3.13	This Study
Dalton MP 9-18		7.6	2013	5	Expanded	8.88	0.288	3.47	This Study
Dalton MP 9-18		7.6	2013	5	Expanded	8.73	0.298	3.36	This Study
Dalton MP 9-18		7.6	2013	5	Expanded	4.60	0.270	3.70	This Study
Cripple Creek 1		5.1	1997	21	Expanded	13.23	0.489	2.04	This Study
Cripple Creek 2	Top	5.1	1997	21	Expanded	11.88	0.398	2.51	This Study
Cripple Creek 3	Bottom	5.1	1997	21	Expanded	11.25	0.413	2.42	This Study
Cripple Creek 4		5.1	1997	21	Expanded	21.51	0.562	1.78	This Study
Cripple Creek 5		5.1	1997	21	Expanded	20.62	0.522	1.92	This Study
Cripple Creek 6	Top	5.1	1997	21	Expanded	17.55	0.460	2.17	This Study
Cripple Creek 7	Bottom	5.1	1997	21	Expanded	4.72	0.298	3.36	This Study
Cripple Creek 8		5.1	1997	21	Expanded	19.41	0.574	1.74	This Study
Quebec Test			1995	1	Expanded	0.51	0.277	3.61	Pouliot and Savard
Quebec Test			1995	3	Expanded	0.8	0.263	3.80	Pouliot and Savard
Quebec Test			1995	5	Expanded	2.7	0.215	4.66	Pouliot and Savard
Averages						**9.116**		**2.990**	
Std. Dev						**6.851**		**0.818**	
Coefficient of Variation						**0.752**		**0.274**	

CHAPTER 3. DATA ANALYSIS AND DISCUSSION

3.1. Comparison with previous analysis

Two locations were sampled for expanded foam board, and one location was sampled for extruded foam board, with a very large difference in service life. Due to limited data, it was inappropriate to compute a ratio similar to those proposed by Esch. Consequently, the methodology reported by the previous authors was applied to previous data and combined with the data collected for this study. The resulting increase in thickness necessary for equivalent performance based on Table 1 would indicate that expanded polystyrene insulation requires a thickness of 1.50 times that of extruded insulation. This ratio is slightly higher than the ratios reported by Esch and by Pouliot and Savard of 1.36 and 1.23, respectively.

However, as stated by Esch, this does not account for the variability in R-values reported. A better approach may be to report the ratio of the average, minus one standard deviation for each type of insulation. That ratio, based on the the average R-values and standard deviations computed in Tables 1 and 2, would be 1.86 for EPS, which is significantly higher than that reported by previous authors. The additional data provided in this study extends the service life of the data set, which accounts for the larger ratio.

Using the same approach, one could estimate a similar ratio for in-service insulation based on the as-advertised R-value. Based on the Alaska specifications for rigid foam insulation, the minimum R-value required is 4.5 (ft)(hr) (ft^2)/(BTU-in) (specification 635-201 Alaska Standard Specifications 2017). Manufacturers of both EPS and XPS claim to meet this specification. Based on the average, the ratio for in-service EPS would be 1.5 and 1.0 for XPS. Using the average minus one standard deviation method, the ratio of in-service thickness would be 2.07 for EPS and 1.12 for XPS.

Another way to compare the products is to review the performance of the in-service products directly. Figure 1 shows that EPS absorbs considerably more moisture over time than XPS and that the uptake of water begins earlier than XPS. This finding is not surprising due to differences in the manufacturing processes. EPS is formed through the expansion of polystyrene beads using steam. The beads are then dried and heat fused in a mold. As a result of the manufacturing process, interconnected voids develop between the beads. The size and number of interconnected voids are a function of the bead size and the density at which the product is produced. This makes the EPS insulation bi-modal in the absorption of water. In the first mode, the free water may move into the insulation through absorption, capillary action, or gravitational forces. Water uptake in this mode will occur relatively quickly.

The second mode of water uptake in EPS is due to water vapor moving into the bead itself. This process is much slower and requires enough vapor pressure to force the water vapor into the bead.

In contrast, XPS is a closed cell structure with few or no interconnected voids. Consequently, essentially no moisture movement occurs by capillary action or gravitational force. The primary infusion of water into XPS is due to the slow movement of water vapor.

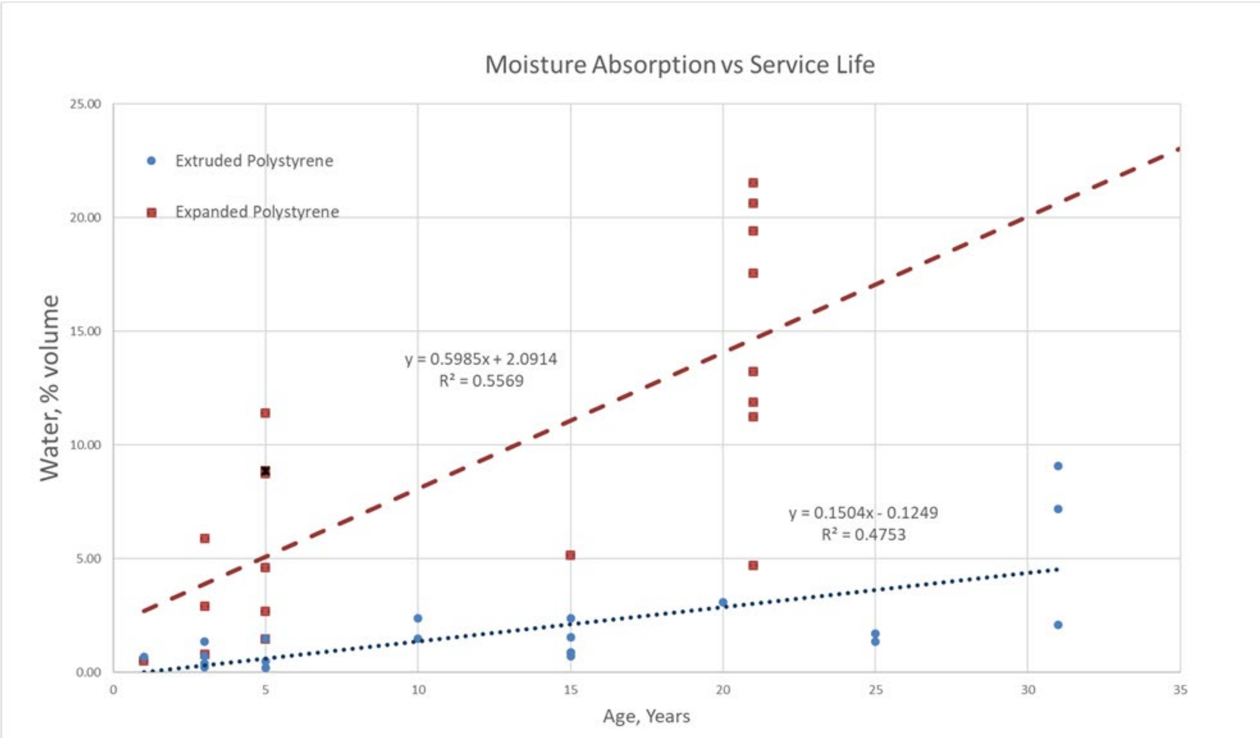

Figure 1 Moisture absorption - service life relationship

3.2. Understanding water absorption

Laboratory studies use either submersion or a guarded hot box with a warm, high humidity side and a cold dry side to test the uptake of water. In the case of submersion tests, the sample is simply submerged in water for a specified period of time. Moisture moving into the sample is primarily liquid water being forced into the pore space by a hydraulic head.

In the case of the guarded hot box, one side is kept at a specified temperature and at relative humidity near 100%. The cold side is kept at a specified temperature. This creates vapor pressure, causing water in the form of vapor to move from one side of the insulation to the other. At some point within the insulation, the temperature and vapor pressure are such that the moisture condenses.

The forces that move moisture within the structure of the insulation are constant. While the distribution of moisture within the insulation may vary, the overall R-value-moisture content relationships are generally repeatable.

Even if the in-situ sample is submerged, these tests do not represent the conditions in a roadway in cold climates. Soil moisture and temperature are continuously changing in the soil. In some cases, the temperature may be warmer on the surface during the summer months and colder on the surface during the winter months. Consequently, the vapor pressure and direction are constantly changing. These variables can change along the roadway as sun exposure, water table, vegetation, and other variables change. The constantly changing environment results in variable moisture distribution within the insulation. This may well explain the variability in moisture content in the insulation. Unfortunately, there appears to be no information about moisture distribution within the insulation layers placed in roadway embankments.

As shown in Figure 1, measured long-term water uptake for XPS reaches a maximum of about 9% by volume after 31 years, while measured long-term water uptake for EPS can range between about 5% and 22% after 21 years. The interconnected voids in EPS, which allows moisture to readily move in and out of the sample as soil suction and soil moisture content change, likely causes the large range of moisture contents in the EPS. However, some water remains, including water that has entered the closed cells in the insulation. Some water that has attached to the sample due to molecular attraction also remains.

To understand this process more fully, it is useful to estimate the amount of moisture that remains in the samples after drying. Only those samples obtained under this study will be evaluated because the requisite data from previous samples are not available. Insulation volume is made up of solids, water, and air. Assuming 1 cubic foot of insulation and knowing the dry density of the insulation, the volume of water that remains in the sample can be calculated using the following equation:

$$V_R = V_t - V_S - V_W - V_A$$

where

V_R = Volume of residual moisture
V_T = 1 ft^3
V_s = Volume of solids comprised of polystyrene. Polystyrene has a specific gravity of 1.05.
V_w = Volume of water removed through drying plus remaining water in closed cells and water molecularly attached to the surfaces within the insulation.
V_A = Volume of air, which is assumed to have no weight.

Since some water remains in the sample after drying, it is unlikely that the R-value will return to the manufactured R-value after drying the sample.

The density of 40 psi XPS is 1.8 lb/ft^3, which equates to 0.0275 ft^3 or 2.75% by volume of the total dry sample. The specific gravity of polystyrene is 1.05.

Referring to Table 1, the average V_w is 6.12% or 0.0612 ft^3 for Golovin, determined by drying the sample to a constant weight. Note that this only removes the free water in the system.

After 31 years, the weight of water in the sample is the initial weight of the sample minus 1.8 lb/ft^3 or an average of 4.93 lb/ft^3, which equates to 0.079 ft^3 of total water in the sample. Subtracting the average moisture loss of 0.0612 ft^3 in the sample due to drying yields about 0.0178 ft^3 or 1.78% of water by volume remaining in the sample after drying. Consequently, after being in service for 31 years, about 24% of the initial 0.0612 ft^3 water remains in the sample. This is due to the inability of the drying process to drive water out of the closed cells in the sample and because some of the water is molecularly attached to the insulation surfaces.

Insulfoam 40 has a density of 2.71 lb/ft^3. The volume of water remaining in the sample was 0.0096 lb/ft^3 or 0.96% of the volume of the sample. This means that, after being in service for 21 years, about 8% of total water remains in the closed cells or is molecularly attached to the surfaces within the sample.

The water remaining in the sample is likely the water that remains in the closed cells, inferring that EPS has a significantly greater number of interconnected voids. This is consistent with the observation that EPS absorbs water more readily than XPS.

3.3. Relationship between R-value and moisture content

Figure 2 shows the relationship between R-value and moisture content. EPS appears be more sensitive to water content than XPS. The in-service moisture content does not exceed 9% for data that includes Golovin, which has been in service for 31 years. Referring to Figure 1, it appears that the uptake of moisture is generally linear.

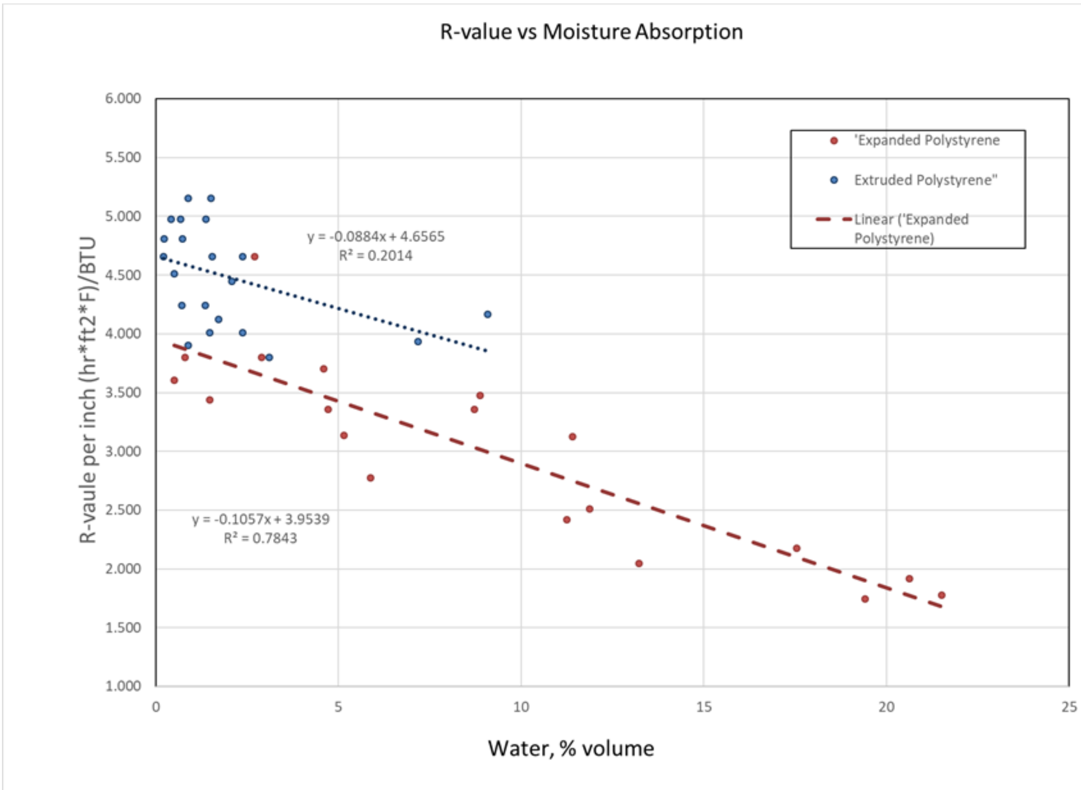

Figure 2 R-value - moisture absorption relationship

There is noticeable variation in the relationship between R-value and moisture content for both EPS and XPS. As discussed earlier, this variation may be due to the distribution of moisture within the insulation. Without further research, the variation cannot be substantiated.

Pouliot and Savard (2003) noted that testing thermal conductivity between hot and cold plates is challenging because thermal stability is difficult to reach. They also noted the difficulty of testing recovered samples due to surface damage and contamination of the insulation from soil adhering to its surface. To minimize these problems, we removed the top and bottom ¼ inch of the surface, removing damaged and contaminated material.

3.4. R-value over time

Figure 3 shows the relationship between R-value with time. For reasons already discussed, one should not expect a high degree of correlation between R-value and service life. However, a clear trend indicates that R-value decreases with time. EPS decreases more rapidly than XPS and appears to become asymptotic to a value of 2.2 at about 30 years. XPS becomes asymptotic to a value of about 4.1 after 30 years. Again, using the methodology proposed by Esch, the ratio of the thickness of EPS to XPS would be

1.86, which is similar to the ratio proposed using the average minus one standard deviation. If we take these values and derive the ratio to the specification of 4.5, we get 2.0 and 1.1 for EPS and XPS, which is close to the values proposed by the average minus one standard deviation.

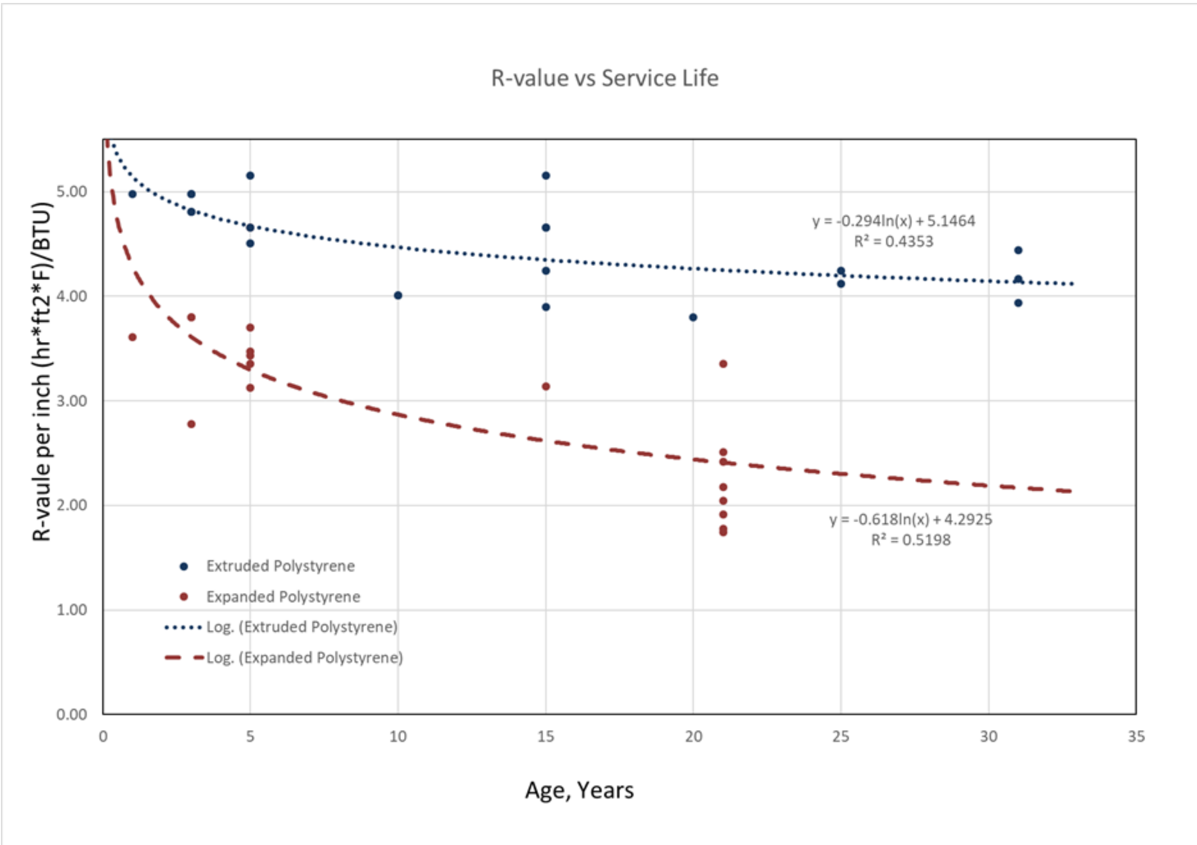

Figure 3 R-value and service life relationship

3.5. Application of thickness corrections

Several ratios of thickness have been presented in this report which can be used to adjust the thickness of the insulation to reflect long-term performance of rigid foam board used in roadway and airport embankments. Because there is no consensus as to which procedure should be applied, if any, the decision of whether to apply a thickness adjustment or what procedure to apply is left to the designer or agency policy.

Two procedures have emerged with alternatives within those procedures, summarized in Table 3. The first procedure is to assume there is no change in the performance of XPS over time and to apply a multiplier to EPS to account for the difference in performance. For example, if the designer estimates that a thickness of 4 inches of XPS is required and EPS is proposed, one of 5 ratios have been provided. Using the average minus one standard deviation multiplier for all available data, the 4 inches determined for XPS would be multiplied by 1.86 to arrive at a thickness of 7.4 inches of EPS.

Table 3 Summary of thickness multipliers

Basis for Multiplier	Multiplier	
	EPS	XPS
Esch (1986) based on average R-value	1.36	1
Pouliot & Savard (2003) based on average R-value	1.23	1
Average based on all data including data from this study	1.5	1
Average -1 standard deviation based on all data	1.86	1
Ratio of asymptotic values from Figure 3	1.86	1
Ratio of average to 4.5 specification	1.67	1.11
Ratio of average minus 1 standard deviation to 4.5 specification	2.07	1.12
Based on ratio of asymptotic value from Figure 3 to 4.5 specification	2.0	1.1

The second procedure would be to determine the required thickness of insulation required at the specified R-value, in this case, 4.5 (ft)(hr) (ft^2)/(BTU-in). The thickness would be multiplied by the multiplier shown in Figure 3 for each product. If an R-value of 20 is required, the thickness required would be 4.4 inches. (20/4.5 = 4.4). Using the multipliers of 2.07 for EPS and 1.12 for XPS, the adjusted thickness, taking the deterioration of in-service R-value, would be 9.2 inches for EPS and 5.0 inches for XPS, respectively.

CHAPTER 4. SUMMARY AND CONCLUSIONS

The data from this study, combined with data from Esch (1986) and Pouliot and Savard (2003), provide considerable insight into the performance of EPS and XPS in roadway and airport embankments. The following observations can be made from the data:

- Data collected from the Dalton Highway showed no statistical difference between older EPS and the newer EPS used on the Dalton.
- The moisture content of both products is quite variable over time. This variation is likely due to the soil characteristics and the varying temperature gradients both spatially and over time. Unfortunately, this interaction is not understood.
- The relationship between R-value and moisture content is not well defined, possibly because of moisture distribution within the insulation.
- EPS appears to be more sensitive to moisture content than XPS, resulting in a lower R-value at the same moisture content.
- The maximum moisture content of EPS was about 22%, with a maximum service life of 21 years. The maximum moisture content of XPS was 9% with a maximum life of 31 years. This difference is likely due to the interconnected voids within the EPS insulation that do not exist in XPS.
- Table 3 provides a summary of the multipliers used in this study. There is no consensus as to how to determine the final thickness of rigid foam insulation.
- If the designer wants to simply compare the in-service R-value ratios, multiply the thickness-indicated multiplier in Table 3 by the thickness of XPS to get an equivalent thickness of EPS.
- If the designer wishes to account for the in-service reduction in R-value, multiply the design thickness by the multiplier for the desired product using one of the three methods indicated in Table 3.
- The characteristics of soil, climate, and available moisture have a significant impact on the uptake of moisture in rigid foam insulation. To gain an understanding of this interaction, it is suggested that unsaturated soil mechanics be integrated into the study of insulation used below grade. Currently available sensors including soil moisture gauges, soil suction sensors, and heat flux meters can be employed to develop an understanding of how R-value in insulation varies with soil type and time.
- Moisture distribution within rigid foam insulation likely impacts R-value-moisture relationships. CT scanners and proper sampling techniques may yield a better understanding of how R-values change as moisture content changes for different applications.
- There is no conclusive explanation for the variability in data. While a better understanding of the interaction of insulation with soil-moisture characteristics would be useful in providing improved design procedures, the data provided here does indicate that the use of R-values as manufactured may not be appropriate. It is left to the designer to decide whether additional thickness is cost-effective.
- The 24-hour immersion test ASTM C272 does not predict field performance. It is recommended that an effort be made to find a replacement test.

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APPENDIX A THIRD PARTY R-VALUE TEST REPORTS

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RADCO
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RADCO TEST REPORT
Test Report No. RAD-6047
Project No. C4128A
Lab No. TL-4054

Rigid Foam Insulation
Tested In Accordance with ASTM C518-10

Prepared for

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by

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Issued: March 26, 2018

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Testing Laboratory

1.0 INTRODUCTION

At the request of the University of Alaska, RADCO conducted Thermal Transmission Property tests on samples of Polystyrene Foam Insulation material in accordance with ASTM Standard C518-10 *Thermal Transmission Properties By Means of The Heat Flow Meter Apparatus*.

2.0 MATERIAL

Four (4) 2' x 2' (609.6mm x 609.6mm) rigid foam insulation panel samples were received at RADCO's Long Beach, CA test facility on February 26, 2018. The panels were selected by University of Alaska personnel and shipped from Fairbanks, Alaska. The source of the samples were taken from the Dalton Highway MP 10, with two taken from the top layer and two from the bottom. The samples were taken 18ft right of centerline in Northbound lane 36 in below surface.

2.1 CONDITIONING

When received, the specimens were wrapped and sealed with polyethylene to preserve their moisture by the client. At the request of the client, four (4) samples were tested as received from the field without conditioning.

3.0 ASTM STANDARD C518-10, THERMAL TRANSMISSION PROPERTIES BY MEANS OF THE HEAT FLOW METER APPARATUS

3.1 TEST EQUIPMENT

1. Steel rule graduated to 1mm
2. Sartorius Model GP3202 electronic digital scale
3. Holometrix Micromek (Metrisa Company) Lambda 2000 Series heat flow meter thermal conductivity instrument

3.2 TEST METHOD

Testing was conducted in accordance with ASTM C518-10. Four (4) 12" x 12"x 2" (304.8 mm x 304.8 mm x 50.8 mm) specimens were tested consecutively at their specified mean temperature of 30˚F as requested by UAF. The recorded data and the results are shown in the following tables. Thickness measurements are as reported by the test apparatus.

3.3 TEST RESULTS

Material ID: SAMPLE TESTS (as received)	1	2	3	4
Date of Test:	3/7/18	3/7/18	3/8/18	3/8/18
Hot plate temperature °F:	50.89	49.52	50.47	50.88
Cold plate temperature °F:	10.84	9.39	10.43	10.90
Mean temperature during test °F:	30.87	29.45	30.45	30.89
Temperature gradient during test °F:	40.05	40.13	40.04	39.98
Specimen thickness as tested (in):	2.0122	2.0881	2.0547	2.0365
Duration of measurement portion of test (hrs:min:sec):	02:19:04	03:33:46	05:05:39	02:34:20
Initial specimen mass (wt.) (gms)	367.21	322.17	322.17	240.95
Final specimen mass (wt.) after test (gms):	368.77	319.20	316.24	235.25
Moisture Content (%)	-0.42	0.92	1.8	2.4
Specimen percent mass (wt.) change:	0.42	-0.92	-1.84	-2.36
Thermal conductivity "k": (BTU.in)/(Hr.ft2.°F)	0.320	0.288	0.298	0.270
Thermal resistance "R" per thickness tested: (Hr.ft2.°F)/BTU	6.3	7.2	6.9	7.5
Thermal resistance “R” per inch: ((Hr.ft2.°F)/BTU-in)	3.1	3.5	3.4	3.7
Density of Specimen (pcf)	4.90	4.27	4.30	3.84

Note 1: Last heat flow meter calibration date: 3/7/18
Note 2: Type of calibration material used: fiberglass

4.0 MOISTURE CONTENT

4.1 TEST METHOD

One (1) 12" x10" x 2" specimen was used to determine the moisture content. The specimen was weighed as received and then dried to a constant weight at 120˚F**.**

Initial Weight: 221.81 gms
Final Weight: 145.09 gms
Moisture Content (2-inch sample) (%): 1.95

The specimen was then tested at its specified mean temperature of 30˚F. The recorded data and results are shown in the following table. Thickness measurement are as reported by the test apparatus.

4.2 TEST RESULTS

Material ID: SAMPLE TESTS (dried)	**5**
Date of Test:	3/14/18
Hot plate temperature °F:	48.89
Cold plate temperature °F:	8.86
Mean temperature during test °F:	28.87
Temperature gradient during test °F:	440.02
Specimen thickness as tested (in):	2.0268
Duration of measurement portion of test (hrs:min:sec):	02:02:59
Initial specimen mass (wt.) (gms):	145.19
Final specimen mass (wt.) after test (gms):	145.09
Specimen percent mass (wt.) change:	0.06
Thermal conductivity "k": (BTU.in)/(Hr.ft2.°F)	0.215
Thermal resistance "R" per thickness tested: (Hr.ft2.°F)/BTU	9.4
Thermal resistance “R” per inch: ((Hr.ft2.°F)/BTU-in)	4.7
Density of Specimen (pcf)	2.34

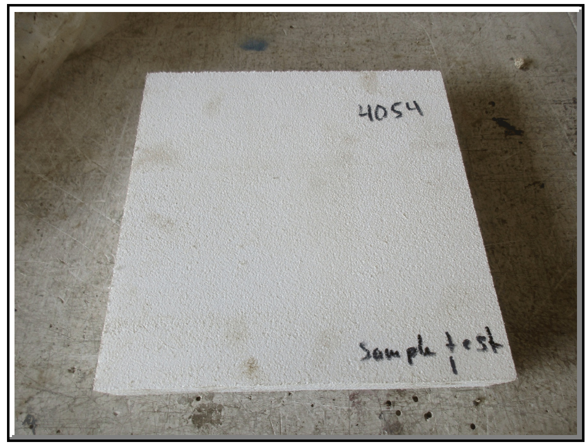
Note 1: Last heat flow meter calibration date: 3/7/18
Note 2: Type of calibration material used: fiberglass

*******END OF REPORT*******

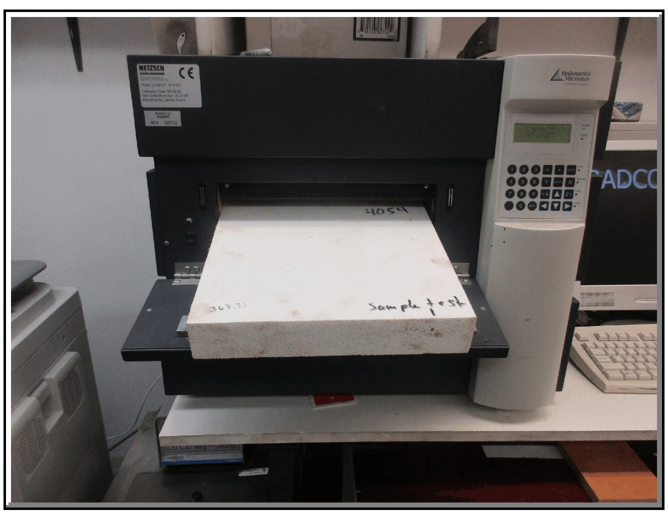
5.0 PHOTOGRAPHS

Sample panel upon removing the polyethylene

Test Specimen



Test Specimen inserted into thermal Conductivity Machine



RADCO
A TWINING COMPANY

RADCO TEST REPORT

Test Report No. RAD-6120
Project No. C4396A
Lab No. TL-4101

Rigid Foam Insulation
Tested In Accordance with ASTM C518-10

Prepared for

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Issued: October 19, 2018

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ACCREDITED

Testing Laboratory

TL-209

1.0 INTRODUCTION

At the request of the University of Alaska, RADCO conducted Thermal Transmission Property tests on samples of Rigid Foam Insulation material in accordance with ASTM Standard C518-10 *Thermal Transmission Properties By Means of The Heat Flow Meter Apparatus*.

2.0 MATERIAL

Eleven (11) 12" x 12" rigid foam insulation samples were received at RADCO's Long Beach, CA test facility on September 28, 2018. The panels were selected by University of Alaska personnel and shipped from Fairbanks, Alaska. Eight (8) expanded polystyrene samples were from Cripple Creek and three (3) extruded polystyrene samples were from Golovan Airport. The samples were obtained from the following locations:

> Cripple Creek samples 1,4 & 5 were obtained adjacent to the culvert, samples 2 & 3, were obtained from top and bottom layers of STA 717+64, 13.6ft Lt, 4.4ft below road surface and samples 6 & 7 were obtained from the top and bottom layers of STA 717+43, 22ft Rt, 5.4ft below road surface.
>
> Golovan Airport sample 1 was obtained from STA 108+46, 268' left 32 in below surface of existing apron, sample 2 was obtained from STA 108+46, 268' left and sample 3 was from STA 10+90, 265' left 32" below elevation of existing apron.

2.1 CONDITIONING

When received, the specimens were individually wrapped to preserve their moisture by the client. At the request of the client, all eleven (11) samples were tested as received without drying. One sample from Cripple Creek and one sample from Golovan were dried and tested.

3.0 ASTM STANDARD C518-10, THERMAL TRANSMISSION PROPERTIES BY MEANS OF THE HEAT FLOW METER APPARATUS

3.1 TEST EQUIPMENT

1. Steel rule graduated to 1mm
2. Sartorius Model GP3202 electronic digital scale
3. Holometrix Micromek (Metrisa Company) Lambda 2000 Series heat flow meter thermal conductivity instrument

3.2 TEST METHOD

Testing was conducted in accordance with ASTM C518. Eleven (11) 12" x 12"x 1" (304.8 mm x 304.8 mm x 25.4 mm) specimens were tested at their specified mean temperature of 75˚F. The recorded data and the results are shown in the following tables. Thickness measurements are as reported by the test apparatus.

3.3 TEST RESULTS

Material ID: Cripple Creek (as received)	1	2	3	4
Date of Test:	10/5/18	10/4/18	10/5/18	10/5/18
Hot plate temperature °F:	92.89	93.19	93.19	92.69
Cold plate temperature °F:	53.87	53.58	53.79	54.05
Mean temperature during test °F:	73.38	73.38	73.49	73.37
Temperature gradient during test °F:	39.02	39.62	39.40	38.64
Specimen thickness as tested (in):	1.0202	1.0219	1.0167	1.0209
Duration of measurement portion of test (hrs:min:sec):	00:32:13	00:35:06	01:00:24	00:36:19
Initial specimen mass (wt.) (gms):	572.28	320.75	305.48	527.04
Final specimen mass (wt.) after test (gms):	560.50	311.41	303.49	523.53
Specimen percent mass (wt.) change:	-2.10	-3.00	-0.65	-0.67
Thermal conductivity "k": (BTU.in)/(Hr.ft2.°F)	0.489	0.398	0.413	0.562
Thermal resistance "R" per thickness tested: (Hr.ft2.°F)/BTU	2.1	2.6	2.5	1.8
Thermal resistance “R” per inch: ((Hr.ft2.°F)/BTU-in)	2.0	2.5	2.4	1.8
Density of Specimen (pcf)	8.80	8.45	8.03	13.71

Note 1: Last heat flow meter calibration date: 10/4/18
Note 2: Type of calibration material used: fiberglass

Material ID: Cripple Creek (as received)	5	6	7	8
Date of Test:	10/8/18	10/8/18	10/10/18	10/10/18
Hot plate temperature °F:	92.74	93.06	93.32	92.91
Cold plate temperature °F:	53.71	53.95	53.26	54.39
Mean teperature during test °F:	73.23	73.51	73.29	73.65
Temperature gradient during test °F:	39.03	39.11	40.06	38.52
Specimen thickness as tested (in):	1.0656	1.0484	1.0291	0.9897
Duration of measurement portion of test (hrs:min:sec):	00:35:05	01:16:41	00:40:33	00:39:42
Initial specimen mass (wt.) (gms):	523.09	451.45	185.35	572.80
Final specimen mass (wt.) after test (gms):	518.37	443.23	183.88	56.50
Specimen percent mass (wt.) change:	-0.91	-1.85	-0.80	-2.10
Thermal conductivity "k": (BTU.in)/(Hr.ft2.°F)	0.522	0.460	0.298	0.574

Thermal resistance "R" per thickness tested: (Hr.ft2.°F)/BTU	2.0	2.3	3.5	1.7
Thermal resistance "R" per inch: ((Hr.ft2.°F)/BTU-in)	1.9	2.2	3.4	1.742
Density of Specimen (pcf)	13.43	11.57	4.98	15.1

Note 1: Last heat flow meter calibration date: 10/8/18
Note 2: Type of calibration material used: fiberglass

Material ID: Golovan (as received)	1	2	3
Date of Test:	10/12/18	10/11/18	10/11/18
Hot plate temperature °F:	93.41	93.51	93.63
Cold plate temperature °F:	53.42	53.23	53.07
Mean temperature during test °F:	73.41	73.37	73.35
Temperature gradient during test °F:	39.99	40.28	40.56
Specimen thickness as tested (in):	1.0208	1.0355	0.9963
Duration of measurement portion of test (hrs:min:sec):	01:18:44	01:08:40	00:37:50
Initial specimen mass (wt.) (gms):	296.35	222.61	116.96
Final specimen mass (wt.) after test (gms):	293.18	217.60	109.18
Specimen percent mass (wt.) change (%):	-1.08	-2.30	-7.13
Thermal conductivity "k": (BTU.in)/(Hr.ft2.°F)	0.295	0.254	0.225
Thermal resistance "R" per thickness tested: (Hr.ft2.°F)/BTU	3.5	4.1	4.4
Thermal resistance "R" per inch: ((Hr.ft2.°F)/BTU-in)	3.4	3.9	4.4
Density of Specimen (pcf)	7.90	5.81	3.23

Note 1: Last heat flow meter calibration date: 10/11/18
Note 2: Type of calibration material used: fiberglass

4.0 MOISTURE CONTENT

4.1 TEST METHOD

Eleven (11) 12" x10" x 1" specimens were used to determine the moisture content. The specimen was weighed as received and then dried to a constant weight at 120˚F.

Samples	CC #1	CC #2	CC #3	CC #4	CC #5	CC #6	CC #7	CC #8	G #1	G #2	G #3
Initial Weight (g)	355.87	320.75	305.48	527.04	523.09	451.45	185.35	572.28	296.35	222.61	116.96
Final Weight (g)	95.82	87.25	84.38	104.22	117.86	106.52	92.58	145.86	117.70	81.50	76.02
Gravimetric Moisture Content (%)	271	267.6	262.03	405.7	343.82	323.82	100.21	292.35	151.78	173.14	53.854
Volumetric Moisture Content (%)	13.23	11.88	11.25	21.51	20.62	17.55	4.72	19.41	9.09	7.18	2.08

Two (2) specimens were then tested at its specified mean temperature of 75˚F. The recorded data and results are shown in the following table. Thickness measurement are as reported by the test apparatus.

4.2 TEST RESULTS

Material ID: SAMPLE TESTS (dried)	Cripple Creek #6	Golovan #3
Date of Test:	10/17/18	10/17/18
Hot plate temperature °F:	93.54	93.53
Cold plate temperature °F:	52.96	52.90
Mean temperature during test °F:	73.25	73.22
Temperature gradient during test °F:	40.58	40.63
Specimen thickness as tested (in):	1.0626	1.0185
Duration of measurement portion of test (hrs:min:sec):	00:27:26	00:26:25
Initial specimen mass (wt.) (gms):	106.71	76.06
Final specimen mass (wt.) after test (gms):	106.69	76.03
Specimen percent mass (wt.) change:	-0.018	-0.03
Thermal conductivity "k": (BTU.in)/(Hr.ft2.°F)	0.227	0.211

Thermal resistance "R" per thickness tested: (Hr.ft2.°F)/BTU	4.7	4.8
Thermal resistance “R” per inch: ((Hr.ft2.°F)/BTU-in)	4.4	4.7
Density of Specimen (pcf)	2.73	2.10

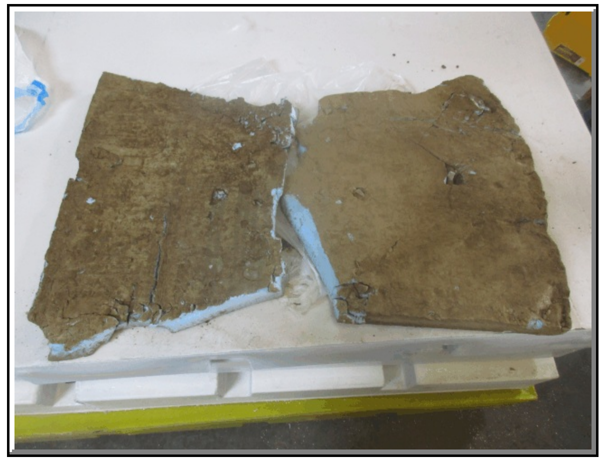
Note 1: Last heat flow meter calibration date: 10/17/18
Note 2: Type of calibration material used: fiberglass

*******END OF REPORT*******

5.0 PHOTOGRAPHS

Test Specimens as received

Cripple Creek Sample



Golovan Sample

Test Specimen inserted into thermal Conductivity Machine